

Young Stars Near Earth: Progress and Prospects
ASP Conference Series, Vol. ???, 2001
Ray Jayawardhana and Thomas Greene, eds.

Evolution of Dusty Disks in Nearby Young Stellar Groups

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Abstract. Given their proximity and age differences, nearby groups of young stars are valuable laboratories for investigations of disk evolution and diversity. The estimated 10-Myr age of groups like the TW Hydrael Association provides a strong constraint on disk evolution timescales and fills a significant gap in the age sequence between 1-Myr-old T Tauri stars in molecular clouds and 50-Myr-old nearby open clusters. I review the results of recent and on-going studies of dusty disks in three nearby groups –TW Hya, η Cha and MBM 12– that suggest rapid evolution of inner disks. However, it is unlikely that there is a universal evolutionary timescale for protoplanetary disks, especially when the influence of companion stars is taken into account.

1. Introduction

Planetary systems are thought to form out of circumstellar disks that are the remnants of star formation (Shu, Adams, & Lizano 1987). Observations of young pre-main-sequence (PMS) stars show that many of them are surrounded by optically-thick disks of solar system dimensions with masses comparable to or greater than the “minimum-mass solar nebula” of $0.01 M_{\odot}$ (see Beckwith 1999 for a review). Infrared emission in excess of stellar photospheric fluxes provides the most readily measurable signature of such disks. Excesses at $\lambda \leq 10 \mu\text{m}$ are found in \sim 50–90% of the low-mass stars in star-forming regions (Strom et al. 1993; Lada et al. 2000).

It has been suggested that circumstellar disks evolve from optically thick to optically thin structures in about 10 Myr (Strom et al. 1993). That transition may mark the assembly of grains into planetesimals, or clearing of the disk by planets. Indeed, low-mass debris disks have now been imaged around several main-sequence stars with ages ranging from 10 Myr to 500 Myr (e.g., Jayawardhana et al. 1998; Holland et al. 1998; Greaves et al. 1998). Since age estimates for early-type isolated main sequence stars are highly uncertain, however, the timescale for disk evolution and planet formation is poorly constrained, and may depend critically on the presence or absence of a close binary companion.

The nearby young stellar groups provide a unique opportunity to investigate the evolution of circumstellar disks into planetary systems. Because of their proximity, these groups are ideally suited for sensitive disk searches at near- and mid-infrared wavelengths. Furthermore, their age range of 1-50 Myrs provides a strong constraint on disk evolution timescales and fills a significant gap in the age sequence between \sim 1-Myr-old T Tauri stars in molecular clouds like

Taurus-Auriga and Chamaeleon and the \sim 50-Myr-old open clusters such as IC 2602 and IC 2391 (Jayawardhana 2000).

2. TW Hydrael Association

The TW Hydrael Association (TWA) consists of \sim 22 co-moving stellar systems (Webb 2001 and references therein) with estimated ages of \sim 10 Myr at a distance of 47–67 pc and dispersed over some 20 degrees on the sky. The members are mostly late-type stars, typically K and M spectral types, and include several binary systems as well as one remarkable quadruple system (HD 98800). There is only one early-type star (HR 4796A).

Over the past three years, we have obtained mid-infrared observations of TW Hya stars using the OSCIR instrument on the Keck II and CTIO 4-meter telescopes. We found that many of the TWA stars have little or no disk emission at $10\mu\text{m}$. Even among the five stellar systems with $10\mu\text{m}$ excesses, most show some evidence of inner disk evolution. We imaged a spatially-resolved dust disk around the young A star HR 4796A (Jayawardhana et al. 1998; Telesco et al. 2000; Fig. 1). The surface brightness distribution of the disk is consistent with the presence of an inner disk hole of \sim 50 AU radius, as was first suggested by Jura et al. (1993) based on the infrared spectrum. The SEDs of HD 98800 and Hen 3-600A also suggest possible inner disk holes (Jayawardhana et al. 1999a; 1999b). The excess we detected for CD $-33^\circ 7795$ is modest, and could well be due to a faint companion. Only TW Hya appears to harbor an optically-thick, actively accreting disk of the kind observed in \sim 1-Myr-old classical T Tauri stars; it is the only one with a large $\text{H}\alpha$ equivalent width (-220 \AA). Recent polarimetric images using the adaptive optics system on Gemini North confirm a nearly face-on disk around TW Hya (D. Potter, private communication), previously detected in scattered light by WFPC2 (Krist et al. 2000) and NICMOS (Weinberger et al. 1999) on HST and in millimeter emission by the VLA (Wilner 2001). However, even in TW Hya, there is evidence for dust settling in the inner disk (D'Alessio 2001) and lower accretion rates (Muzerolle et al. 2001) compared to classical T Tauri stars (CTTS) in Taurus.

If most TWA stars are \leq 10 Myr old, the above results suggest that their inner disks have already depleted either through coagulation of dust or accretion on to the central star. The fact that only one (TW Hya) out of 16 systems we observed shows classical T Tauri characteristics (compared to \sim 50–90% of \sim 1-Myr-old stars in star-forming regions) argues for rapid evolution of inner disks in pre-main-sequence stars. However, it is unlikely that there is a universal evolutionary timescale for protoplanetary disks, especially when the influence of companion stars is taken into account. For example, we have detected thermal emission from a dusty disk around the primary, but not the secondary, in the Hen 3-600 binary system (Jayawardhana et al. 1999a). Comparison with the median spectral energy distribution of classical T Tauri stars suggests that the disk around Hen 3-600A may be truncated by the secondary. Sitko et al. (2000) find that the $10\mu\text{m}$ silicate emission feature in TW Hya is similar to that of other CTTS whereas it is weaker in HD 98800 and almost non-detectable in HR 4796A.

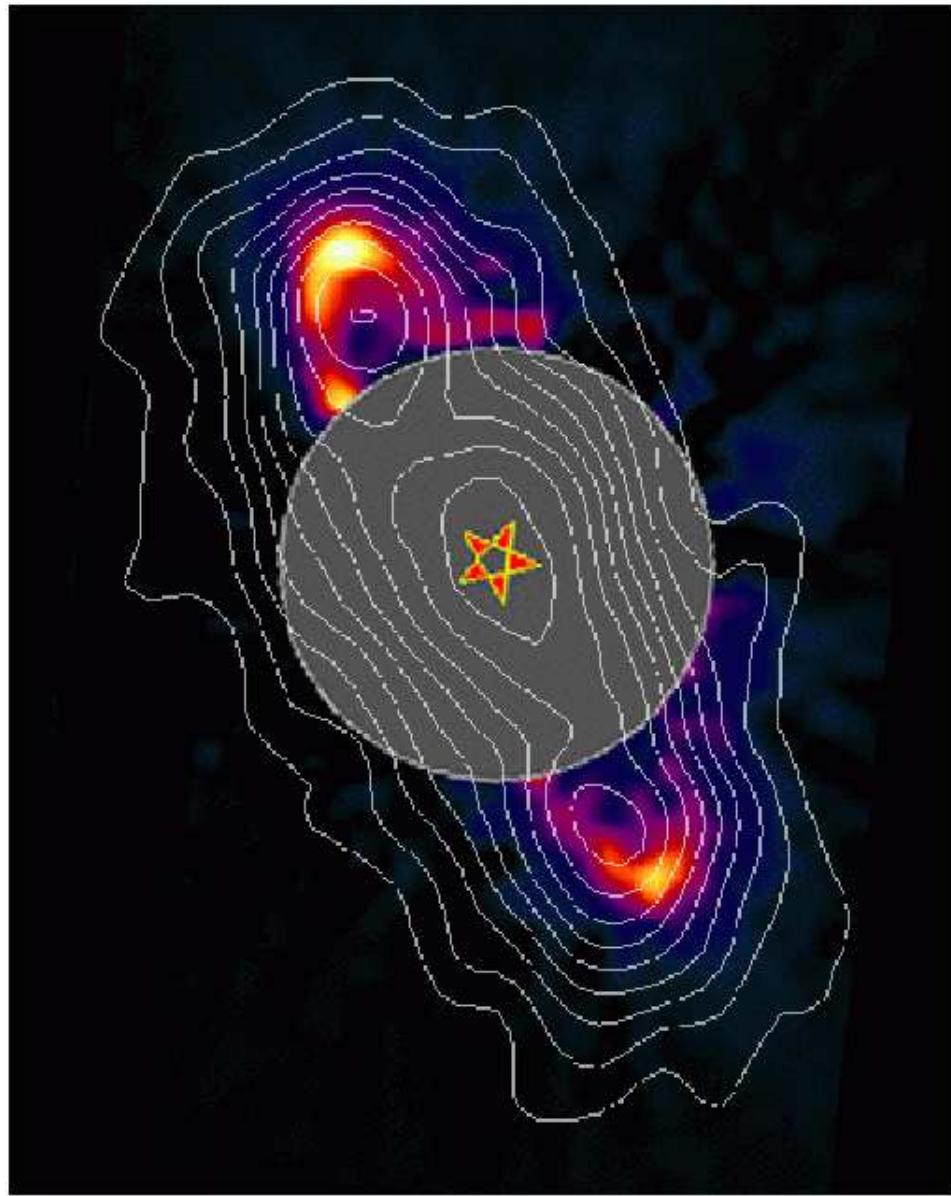


Figure 1. Overlay of Keck/OSCIR $18.2\mu\text{m}$ contours on the $1.1\mu\text{m}$ HST/NICMOS coronagraphic image of HR 4796A disk. From Telesco et al. (2000).

3. η Chamaeleontis

η Cha is a compact cluster of about a dozen stars at \sim 97 pc, far from any obvious molecular material (Mamajek, Lawson & Feigelson 1999). Among the 12 previously known members of the η Cha cluster, only 2 have H α equivalent widths larger than 10 Å, suggestive of disk accretion. Preliminary results of our February 2001 mid-infrared observations using the TIMMI2 instrument on the ESO 3.6-meter telescope confirm that none of these 12 stars have large excesses consistent with optically-thick disks. However, Lawson (2001) reports the identification of a new CTTS associated with the cluster, and another member (RECX 11) is listed in the IRAS Faint Source Catalog as showing a far-infrared excess. Other η Cha stars may have optically thin disks with central cavities, as is the case in several TWA stars, but our analysis is not yet complete.

4. MBM 12

Based on *ROSAT* detections and ground-based follow-up optical spectroscopy, Hearty et al. (2000) identified 8 late-type young stars in the high-latitude cloud MBM12 as well as two main-sequence stars in the same line-of-sight which may or may not be related. While there is some uncertainty in the distance to MBM 12 (Luhman 2001), it is likely to be a younger group than TW Hya and η Cha, perhaps only 1-3 Myr in age.

Recently, we have conducted the first investigation of protoplanetary disks in the MBM 12 group, using mid-infrared imaging with Keck and UKIRT and optical spectroscopy with the Kitt Peak 4-meter telescope (Jayawardhana et al. 2001). The ($K - L$) and ($K - N$) colors we derived unambiguously show significant mid-infrared excess from six MBM 12 stars –LkH α 262, LkH α 263, LkH α 264, E02553+2018, RXJ0258.3+1947 and S18. In all six cases, the colors are consistent with thermal emission from optically-thick inner disks. The other two PMS stars –RXJ0255.4+2005 and RXJ0306.5+1921– do not show a measurable mid-infrared excess within the photometric errors, allowing us to rule out such disks. HD 17332 and RXJ0255.3+1915, the two main-sequence stars in the line-of-sight to MBM 12, also lack evidence of warm circumstellar material. Four of the objects –LkH α 262, LkH α 263, LkH α 264 and E02553+2018– show two components in the H α line, and are probably close binaries (Fig. 2). An H α equivalent width greater than 10 Å is generally considered to be the accretion signature of a classical T Tauri star with a circumstellar disk (Herbig & Bell 1988). A smaller equivalent width signifies chromospheric activity, but no accretion. Therefore, mid-infrared excess we measure should be correlated with large H α line widths. Indeed, this generally holds true for MBM 12 stars with one notable exception: E02553+2018 has a large mid-infrared excess but weak H α line emission. We tentatively suggest that E02553+2018 is a candidate for harboring circumbinary dust.

The disk fraction we find in MBM 12 –75%– falls in the middle of the range reported for other star-forming regions like Taurus and Trapezium, but is significantly higher than in TWA and η Cha. Preliminary results of recent 3mm OVRO observations of MBM 12 stars suggest that their disk masses fall in the low-mass tail of the Taurus CTTS distribution (Hogerheijde et al. 2001).

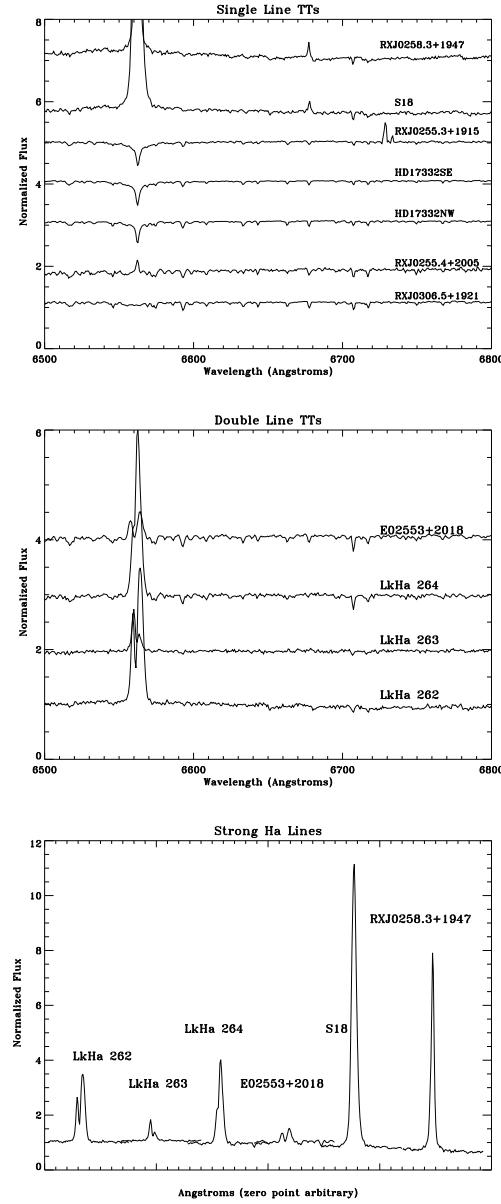


Figure 2. The optical spectra of single-line (*top panel*) and double-line (*center panel*) systems among MBM 12 stars. Bottom panel shows detail of the $H\alpha$ lines of strong emitters. From Jayawardhana et al. (2001).

Acknowledgments. RJ holds a Miller Research Fellowship. This work was supported in part by a NASA grant administered by the AAS.

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